Occupational Ergonomics
Module (Lecture) 15

Presenter

Capt Mario E. Fajardo M.D., USPHS
Internist/Flight Surgeon
Chief, Occupational Medicine

DISCLOSURE**:**

Capt Fajardo does not have any financial arrangements or affiliations with any corporate organizations, which might constitute a conflict of interest with regard to this continuing education activity.

Lecture 15–objectives:

Understand the Definition of Ergonomics
Learn Basic Ergonomic Principles
Explain the Specialized Areas of Ergonomics: Human Factors Engineering; Anthropometry; Biomechanics; Work Physiology
Describe association between Musculoskeletal Disorders and Workplace Factors
Learn about Work Stress: Shift Work and Mental Fatigue
Understand the Ergonomic Standards
Evaluate and Design an Ergonomic Stress-Free Workstation

Required reading: (Following attached documents)

Appendix A: Checklist for Evaluation of Ergonomic Stress for Industrial Shops
Appendix B: Checklist for Evaluation of Stress at Workstations
Appendix C: Web sites for Ergonomic Information
Office Ergonomics ANSI VDT Standards

ERGONOMICS

Ergonomics is the study of work and human-machine systems. It is the science of fitting workplace conditions and tasks demands to the capabilities of human operators. Ergonomists study humans at work and evaluate the stresses that occur in the work environment and the ability of workers to deal with those stressors. The goal of ergonomics is to recognize the mental capabilities and limitations of the worker as he/she interacts with the work environment. Ergonomics is also recognized as the science that deals with musculoskeletal disorders (MSD's). MSD's refers to conditions affecting the nerves, muscles,

tendons, ligaments and other supporting structures. It is essential for providers to understand the relationship between exposure to physical work factors and the development of these conditions in order to identify the exposures amenable to preventive and therapeutic interventions.

Ergonomics covers a wide range of specialty areas such as occupational biomechanics, anthropometrics, human factors engineering and work physiology.

Human Factors Engineering- this field of interest addresses work related information processing requirements. Operational applications include the evaluation and design of displays and controls for preventing injury and illness and minimizing the likelihood of error while maximizing work productivity. Examples would include the instruction booklet for the operation of the instrument or machine or the displays or illustrations on gauges, dials or emergency buzzers.

Work Physiology- this area concerns primarily with the prevention of localized or whole body fatigue imposed by the metabolic demands of given work practices and the response of the cardiovascular, musculoskeletal, and respiratory systems. Occupational fatigue has been described as a physiological, psychological, and mechanical process, which leads to the inability to maintain work performance.

Anthropometrics- this is a specialized area of interest concerned with the statistical measurement of body size and the utilization of this information in the design of tools, facilities, equipment and protective gear to fit the individual. One example of the operational application of this principle can be seen in the aviation community. Prospective student pilots are subject to anthropometric measurements to determine the best suitable airframe that could be safely operated provided the physical limitations of the individual and cockpit configuration of the particular aircraft.

Occupational Biomechanics- this particular field of interest deals with the mechanical properties of human tissue and its response to mechanical stress. Occupational stressors can lead to overt trauma that is usually recognized, however, many other stressors in the same environment can produce subtle changes that can lead to cumulative injuries and disorders. Cumulative trauma commonly affects the soft tissue areas, such as nerves, tendons, muscles, tendon sheaths and ligaments. The overall rate and prevalence of these disorders is not known but evidence suggests they are a major cause of lost productivity and absenteeism. In ergonomics, stressors are commonly external sources of stress that manifests on the worker as a form of strain. For example, the force required for completing a particular task would be a stressor, while the overexertion injury caused while applying such force would represent a strain. These stressors can affect any part of the body but most commonly affect the lower back and upper extremities.

CUMULATIVE TRAUMA DISORDERS

Cumulative trauma disorders refers to a group of chronic muscle, tendon, and nerve related disorders caused, aggravated or precipitated by repeated or sustained exertions. The most common occupational risk factors implicated in the development of CTD's include: repetitive or sustained exertions, forceful exertions, certain wrist postures, localized mechanical stresses, low temperatures, and vibration.

Since the 1970 passage of the Occupational Safety Health Act (OSHA) employers are required to maintain a report of all cumulative trauma disorders (CTD's). Employers are supposed to monitor the incidence of these disorders and intervene when new cases or high-incidence jobs are identified. OSHA records and workman's compensation reports indicate the persistent underestimation of the affliction of cumulative traumatic disorders. Although the overall incidence and severity of CTD's in the U.S. is not available, these disorders are still a major cause of impairment and disability.

For the past 25 years the Bureau of Labor Statistics (BLS) routinely gathered data on occupational illnesses and injuries by random sampling of approximately 250,000 private sector work sites. This Annual Survey of Occupational Injuries and Illnesses was last reported in 1994. As of that date it was reported that approximately **705,800 cases (32%)** of all the injuries reported were the result of overexertion or repetitive motion effects. This was further identified as follows:

367,424- overexertion (lifting)- 65% back
93,325- overexertion (push/pull)- 52% back
68,992- overexertion (holding/carry)- 58% back
83,483- overexertion (unspecified)
92,576- repetitive motion-55% wrist; 7% shoulder; 6% back
47,861- overexertion- shoulder (total from across all three overexertion categories above)

The aforementioned data conflicts to a certain degree with recent published information about workplace injuries. Excerpts from an article printed in the Washington Times (Copyright © 2001 News World Organization, Inc. All rights reserved) reported the following findings*: [In recent years the American workplace has become a safer place. Evidence indicates the risk of dying on the job today is one third what it was 20 years ago. Reportedly occupational injuries in the private sector have declined 29% since 1980. Between 1992 and 1997, the number of ergonomic injuries dropped by 22%. This corresponds with the long-standing trend of workplaces getting less and less dangerous. The National Safety Council Reports the average worker is eight times safer on the job than off he job. The best predictor of back trouble is job satisfaction- with unhappy*

workers more prone to discomfort. To the extent a problem exists, there is no reason to think federal regulation is needed to solve it].

As most are aware the proposed and much anticipated Occupational Health and Safety Organization's (OSHA) Ergonomic Standards signed into law during the weaning days of the Clinton administration was repealed by the incoming Bush administration perhaps as a result of some of these conflicting reports. Nevertheless, approved and enforceable ergonomic standards for the private sector remain in place. Medical providers must remain attentive to the prevalent conditions that continue to produce significant injuries and illnesses despite the workplace improvements and safety practices implemented over the past several years.

LOW BACK PAIN

Approximately eight out of ten adults will have back pain at some point in their life. Low back pain is the second most common cause for clinic visits and the most common cause of absenteeism among workers 25-45 years of age. Approximately 2% of back injuries can be considered a disability. Low back pain accounts for 21% of all reported workplace injuries with overexertion being considered the most common cause. Overexertion has been associated with 25% of reported low back injuries: 67% from lifting/ 20% from pushing or pulling. The exact anatomic cause of low back problems remains unclear. Most times the symptoms are blamed on poor muscle tone, muscle tension, ligament or muscle tears, or joint problems, although muscular strains resulting from a failure of the musculo-tendinous junction resulting from high tensile loads are suspected. In the older worker population, degenerative disease is also considered a major etiology for low back problems. Degenerative disc disease being the result of repeated episodes of high disc compression forces with resultant multiple cartilaginous end plate fractures, sclerosis of the end plate, and ultimately disc degeneration. High intradiscal pressures are attained when holding particular objects or assuming certain postures while attempting to complete an assigned task.

Experiments have been conducted in volunteers to directly measure intradiscal pressure while assuming various positions and holding various objects. Based on some of these experiments, the Institute for Occupational Safety and Health (NIOSH) in 1981 adopted a disc compression criterion called the "Action Limit" for manual lifting. This same criterion is now found in the 1991-revised NIOSH guide for Manual Lifting and is now known as the Recommended Weight Limit (RWL). Following this guideline compression forces on the disk should not exceed 770 lbs. (350 kg).

The criteria for the RWL is as follows:

Compressive force less than 770 lbs.

1. Greater than 75% capability for women; 99% for men (based on strength).
2. Energy expenditure < 3.12 kcal/min near floor; < 2.18 kcal/min above bench height.
3. Nominal risk of low back pain based on epidemiological data.

The NIOSH lifting guide is based on the principle of "an acceptable weight limit for a standard lifting location" with the corresponding weight, called a "load constant" defined as 51 lbs. Various (six) multipliers modify this load constant before arriving at the RWL equation. The multipliers are the horizontal (HM); vertical (VM); distance (DM); frequency (FM); asymmetry (AM); and coupling (CM). The RWL formula is as follows:

RWL= (load constant) x (HM x (VM) x (DM) x (FM) x (AM) x (CM)

Overexertion injuries result from a mismatch between the worker's capabilities and the demands of the job. If the worker's capabilities exceed the job requirements then the task can be accomplished. On the other hand, if the job demands exceeds the worker's capabilities, an overexertion injury can result if the task is attempted. Epidemiological evidence suggests that when the strength demands of a particular task exceed the worker's capabilities there is a three-fold increase risk of musculoskeletal injury. Researchers estimate that nearly one-third of compensable low back problems exceed the maximum acceptable weight for 75% of women. The aerobic demands of the job may also lead to overexertion injuries. Repeated bending, climbing, and lifting in addition to carrying static weight loads add significantly to energy expenditure. Researchers have developed models to help calculate the energy expenditure for defined tasks such as lifting, carrying or walking. Incorporating the weight of the object being handled, the distance and speed, point of origin and destination, and distance heights of lifting and lowering, the energy expenditure for the task can be accurately calculated.

Another factor known to cause overexertion injuries is the posture of the worker while performing a task. Static postural stresses inferring prolonged awkward postures, such as bending below knee level, over-the shoulder reaching and prolonged side-to-side bending may lead lo localized muscle fatigue and injury to the supporting musculoskeletal structures.

Despite the technological advances of today, the exact cause of low back problems can only be determined in a few individuals. The physical conditioning of the person, emotional stress, long periods of inactivity, heavy labor, and pre-existing health conditions can induce an episode of low back pain or make symptoms worse. Obtaining an adequate physical examination, with appropriate diagnostic procedures, prompt medical intervention with the initialization of

analgesia, non-steroidal medications, and physical therapy is imperative in achieving a faster recovery and return to work. Patients with recurring discomfort may be advised to apply cold packs at home within 48 hrs of the onset of symptoms and heat application for symptoms lasting longer than 48 hrs. Spinal manipulation may be beneficial in some people in the first month of low back symptoms. This may be advisable if the provider has a clear understanding of the etiology of the back discomfort. Other treatment methodologies available include the application of traction, massage, biofeedback, ultrasound, transcutaneous nerve stimulation (TENS) and acupuncture. Bed rest for 24-72 hours may be recommended, especially if pain is associated with muscular spasms. Longer periods of rest, however, have been found to be potentially harmful as they induce weakness of other musculoskeletal structures. Advising the patient to wear comfortable clothing and shoes, avoid prolonged sitting or standing, not to carry heavy loads, placing a pillow below the needs while supine or a rolled towel in the lumbar spine while driving, are simple tips that may expedite recovery. Advising the worker to resume gradual activities, such as walking short distances, using a stationary bicycle or swimming and providing instructions on proper lifting techniques before returning to work may prevent an undesirable relapse. Workers with recurrent work related low back pain should have an ergonomic assessment performed to determine both the demands of the job and the capabilities of the worker. Changing jobs may be a suitable alternative to permanent disability and/or continuing diminished work productivity.

UPPER EXTREMITY DISORDERS

Each year thousands of workers in the U.S. report work related musculoskeletal problems such as tendonitis, carpal tunnel syndrome, and epicondylitis associated with work related activities such lifting, pushing or pulling. These musculoskeletal disorders develop over a period of weeks and are the leading cause of disability among persons during their working years. The most common risk factors implicated in these disorders are repetitive movements, vibration, low temperatures, mechanical stress, posture, and inappropriate force. Although these disorders can occur anywhere in the body, the upper extremities are most commonly affected. An evaluation of the effects of each of these stressors will be discussed in greater detail.

Repetitive Movements-

The number of exertions per hour or shift can be calculated from work standard and methods analysis. Some researchers have determined that an action, which lasts greater than 50% of a cycle time or a cycle time greater than 30 seconds, is “high repetitiveness”. This definition has proved to be a good predictor for the development of upper extremity symptoms. Repetitiveness also increases the forcefulness of the exertions required to complete the task.

Vibration-
Upper extremity disorders have been associated with the use of the hand to operate vibrating tools. Vibration may increase the force required to complete a task by impairing sensory feedback or by the tonic vibration reflex. Vibration exposure results from gripping power tools, holding the controls of a power machine, using percussion tools or using grinding machines. Unfortunately, vibration alone cannot be isolated in order to determine its effects from those induce by force or repetitive movement.

Low Temperature-
Cold temperatures affect manual dexterity and tactile sensitivity. Exposing fingers to cold exhaust from pneumatic instruments or working in a cold environment with cooling of the skin to 0-20 degrees Centigrade has a profound effect on strength and sensitivity. Cold temperatures or the use of poor fitting gloves affect the force required to complete a task by impairing sensory feedback, potentially leading to muscle strains and sprains. Well fitting gloves, on the other hand, may improve the coefficient of friction and reduce the force of the action. The hand should be kept above 25 degrees Centigrade to minimize these effects.

Mechanical Stress-
Localized mechanical stresses are caused by physical contact between a part of the body and a tool or instrument. Typically this involves contact with a hard or sharp instrument. Forceful gripping of tools with small diameter handles has been associated with compression of the thenar branch of the median nerve leading to atrophy and paresthesias. Use of hammers, chisels and similar instruments has been associated with this condition. Localized compression has also been associated with trigger fingers by the effect on tendons or tendon sheaths.

Inappropriate Force-
The higher the force of the exertion the greater the risk for upper extremity symptoms. The forcefulness of the task is the most significant risk factor in upper extremity disorders. The amount of force exerted by the fingers to hold an object is proportional to the force causing it to slip out of the hand and inversely proportional to the slipperiness of the object. More strength is required to exert a certain amount of force with gloves than without gloves.

Posture-
Awkward postures affect the maximal force required/applied to a given task. Grip force decreases to approximately 60 lbs if the wrist is flexed at 45 degrees and decreases to 75 lbs if the wrist is extended to 45 degrees. The type of grasp is also important as it affects the magnitude of the force required to perform a task. A pinch grasp increases the tensile loads on flexor tendons to the fingers to a greater extent than a power grasp. However, posture alone is not considered to be a significant risk factor in the development of upper extremity disorders but

does affect the forcefulness required for the task. Awkward postures of the shoulder, elbow, wrist, or hand may result in a CTD. These would include excessive shoulder elevation, deviated wrist postures, extreme elbow postures, and pinch type grip of working tools. One should be aware that awkward postures might result from a poor layout of the workstation or an equipment design as well as operator function.

Following is a list of the most commonly recognized work-related musculoskeletal disorders:

Tendinitis (tendonitis)- irritation/inflammation of a tendon as a result of repetitive forces or stress on a particular muscle-tendon unit.

Lateral Epicondylitis (tennis elbow)- irritation/inflammation of tendon units over lateral aspect of elbow resulting from impact or jerky, throwing motions.

Medial Epicondylitis (golfer's elbow)- irritation/ inflammation of tendon units over medial aspect of shoulder resulting from repeated forceful rotations of the forearm together with bending of the wrist.

Tenosynovitis- irritation/inflammation of a tendon or its tendon sheath resulting from repetitive movements causing the tendon to slide along its sheath in a rapid or frequent manner.

Synovitis- irritation/inflammation of the inner lining of the membrane surrounding a joint or tendon.

Stenosing Tenosynovitis of the finger (trigger finger)- progressive constriction of a tendon resulting from an irritation on the surface of the tendon or inflammation of its tendon sheath leading to restriction of free movement.

de Quervain's disease- stenosing synovitis of the tendons of the radial side of the wrist, leading to constriction with resultant withdrawal of the thumb away from the hand and limited thumb movement.

Raynaud's phenomenon (white finger/vibration syndrome)- reflexive constriction of the small arteries causing fingers to turn pale/white (intermittent blanching), cold, numb and tingly. Condition may result from the extensive use of vibrating tools.

Thoracic outlet syndrome- compression of the nerves and blood vessels between the neck and shoulders causing numbness of the fingers and hands. Condition is caused/aggravated by positional activities such as raising arms high above shoulders or pulling shoulders back and down.

Carpal Tunnel Syndrome- compression of the median nerve as it traverses under a broad dorsal ligament (carpal tunnel) on the wrist causing pain tingling and numbness of the wrist and hands. This condition is precipitated by chronic unnatural positions of the wrists (typing), direct pressure on the median nerve by sharp objects or hard work surface edges or tools.

Preventing Repetitive Muscle Injuries-

Repetitive muscle injuries are the result of doing simple actions over and over again. During our workday we raised the arms above our heads, bend the wrists and flex the elbows into awkward positions as part of doing the job. When this actions are repeated in a frequent basis they can become injurious. This repetitive trauma may not be apparent for years after the initial injury and may last for years after a disorder has been diagnosed. The key to preventing such injuries is to play it smart. By now it should be clear that repeating the same motion, holding the body in awkward positions, using too much force and performing the same activity over prolonged periods of time is a setup for this type of injury.

It is essential for the worker to become familiar with the job requirements and the type of tools needed to do the job. One should choose the right size and shape tool and select those with the least vibration. If unsure the worker should contact the supervisor. One should also know how to stand at the workstation to prevent awkward positioning of the extremities, learn to use the whole hand whenever possible, avoid pinching actions and maintain the wrist in a neutral position when working. Other actions such as keeping the elbows bent to keep loads close to the body when lifting, using lighter loads, and allowing for a safe work zone are also important. It is also important to remind the worker to take adequate rest periods, apply ice compresses and take analgesics if symptoms appear, and apply adequate relaxation and stretching methods to prevent injuries.

FATIGUE

One common result of all the aforementioned musculoskeletal disorders is muscle fatigue. Researchers have developed a physiologic model for assessment of upper-extremity disorders that cites muscle fatigue as a major contributor of these disorders. Fatigue is a transient loss of work capacity resulting from a preceding work activity. It is manifested by a feeling of decreased strength, loss of muscle control and discomfort. Fatigue increases and work capacity decreases as a result of increased strain due to increased duration of exertion. This can be assessed by the following formula:

% Maximal Force = required force ÷ worker's maximal force

Two types of fatigue are described in the occupational setting: whole-body fatigue and localized fatigue. The former affects many tissues while the latter occurs only in affected ones. *Localized fatigue* is usually reversible with full recovery within 24 hours. It often has a direct cause and effect relation between symptoms and the type of work being performed (i.e. holding a suitcase, gripping a tool), which can be resolved by modifying the work activity. It can also reflect an underlying musculoskeletal or neurovascular problem. Localized muscle fatigue is a reversible physiologic state that leads to the accumulation of waste products, depletion of energy reserves or hypoxemia due to impaired blood flow. *Whole-body fatigue*, on the other hand, tends to occur when multiple muscles are activated in the performance of a certain task (i.e. running, walking, shoveling). Measuring the estimated energy expenditure rate of the particular task being performed can assess the effects of whole-body fatigue. This can be done through one of several methods, including measuring oxygen uptake, estimating the work energy requirements from an elemental task analysis and by using extrapolated data from a similar known task. Energy expenditure and resultant whole-body fatigue can be controlled by an effective good job design that minimizes unnecessary repetitive work activities.

Another type of fatigue often ignored is mental fatigue. Mental fatigue is characterized by degradation in ability to sustain adequate performance in mental tasks due to the physical and mental demands of the previous workday's activities. Field experiments have demonstrated that the length and intensity of the previous workday may have negative effects on mental performance by impairing mental capacity directly or affecting the willingness to spend mental capacity on the performance of a given task. Studies indicate that the optimal workweek to be 48 hours long and the ideal workday 8-9 hours with periodic scheduling of rest periods. Optimal scheduling leads to improved productivity and decreased absenteeism. The changing character of the American workplace creates an emphasis on the manipulation of information and processing of abstract data with increasing demand on, perceptual, cognitive, and psychomotor functions as well as mental processing. Mental fatigue, therefore, is a deficit in the cognitive-energetic control mechanisms in the management of mental tasks demands. In other words, it is a problem with being unable, or not having the necessary attention span, to complete the actual task.

The available research has failed to prove a statistical significance in performance impairment between 8 and 12-hour work periods. However, the length of the preceding workday activities, lack of rest (sleepiness), inadequate rest periods, and shift work beginning before 0700 hours or night shift work have a negative effect on performance. Attention needs to be paid to the temporal structuring of work times on mental task performance. Coast Guard medical providers need to be attentive to the fact that many enlisted and junior officers often have secondary jobs that causes them to work back-to back shifts. From search and rescue and drug interdiction operations to routine maintenance of boats, aircraft and machinery as well as the handling of message traffic and radio

signals, Coast Guard missions require maximum alertness. Remember that prolonged mental effort investment (mental fatigue) may adversely affect well-being and health by the sustained activation of physiological processes linked to stress reactions.

Work-Stress

Human physiological and psychological functions follow a 24-hour cycle. For example, the human body temperature is lowest at 4 AM when most individuals are sleep; it rises upon awakening; gradually increases as activity and alertness also increase and peaks around 6 PM. Human biological systems are entrained by daily changes in light and dark with daily biological variations occurring in a daily cycle known as the *circadian rhythm*. People are diurnal and adjustment of the internal biological clock to conditions that alter the synchronous relation between the body's temperature cycle and activity level are limited and often undesirable.

Automation and technology has led to continuous 24-hour operations. The resulting work schedules are dictated by computerized systems with little or no attention provided to human needs, limitations or preferences. Failure to address the limits of human components typically results in decreased work flexibility, extended workdays, and irregular work hours. Ideally, work schedules should consider all the variants that affect a worker's performance capabilities and well being. Some of these variables include:

Environmental factors
Training and education
Health status
Job duties
Age/Seniority
Chronobiology
Marital status
Eating and drinking habits
Cultural and Individual differences

Shift Work

The term *SHIFT* usually refers to a set of hours an individual or group is scheduled to work. In the operational setting, it often it refers to a specific category of work hours such as:

First Shift- day or morning work lasting 8 hours between 0600-1700
Second Shift- afternoon/evening shift lasting 8 hours betwen1500-0100
Third Shift- night/graveyard shift between 2200-0700

Many work shifts are composed of permanent hours though some have rotating or irregular hours. These are in turn affected by shift breaks, non-work-days, compressed work schedules and the continuity of the operations. All these work variations affect the internal biological clock and not surprisingly the biggest effect is the impairment in the quality and quantity of sleep. This is further affected by individual differences in the usual sleep length, which makes it difficult to predict, difficulties to be encountered by individual workers assigned to particular work shifts. Occupational “sleep” studies have demonstrated that workers on the third shift sleep least; workers on the second shift sleep the most; and the first shift workers fall in between. Workers on all three shifts sleep longer during their non-work days but not enough to compensate for the sleep lost during the workdays. Another specific health effect of shift work is the reported incidence of gastrointestinal ulcers among shift workers, which has been reported to be 2-8 times higher than among day workers. Cardiovascular and nervous system disease have not been found to be higher than among the general population and no clear distinction has been found on increased feelings of general fatigue and malaise reported among shift workers when compared to day workers.

Based on the literature, it can be summarized that shift work and in particular the night shift results in impairment of sleep patterns, a higher incidence of gastrointestinal and digestive problems, potential exacerbation of pre-existing health conditions and influences the action of prescribed medication. It can also be said that prolonged exposure to shift work does not produce an adjustment on sleep length and that older workers have a more difficult time adjusting to shift work. As a final note, compressed work schedules are becoming more popular and are well received by both management and worker with no clear evidence of any negative effects on worker safety and health. However, in the occupational setting this presents an often-overlooked problem with the effects of chemical exposures. Most threshold limits for chemical exposures and physical hazards are based on an 8-hour workday. The cumulative effects of exposures based on a 10-12 hour workday have not yet been determined. It is important for the medical provider to be cognizant of the cumulative effects of chemical exposures, fatigue and the complications associated with secondary employment and adherence to the motto *SEMPER PARATUS*.

Proceed to Required Reading and Post-Test